

Claims:

1. A photo-electrolytic catalyst system for hydrogen production from water, said catalyst system comprising:

- (a) a first semiconductor material with a non-zero energy gap E_{g1} which, in response to an incident radiation having an energy greater than E_{g1} , generates electron-hole pairs as charge carriers; and
- (b) at least a first facilitating material in electronic contact with said semiconductor material to facilitate separation of the radiation-generated electrons from the holes to reduce the probability of charge carrier recombination.

2. The catalyst system as defined in claim 1, wherein both said first semiconductor material and said first facilitating material have at least one dimension being nanometer-scaled, smaller than or equal to 100 nm.

3. The catalyst system as defined in claim 1, wherein at least one of said semiconductor material and facilitating material is porous.

4. The catalyst system as defined in claim 1, 2, or 3, wherein said first facilitating material comprises an electron-drawing atom, molecule, or ion.

5. The catalyst system as defined in claim 1, 2, or 3, wherein said first semiconductor material comprises an element or compound selected from the group consisting of group IV semiconductors, III-V compounds, II-VI compounds, mixed crystals of II-VI compounds, mixed crystals of III-V compounds, I-III-V₂ compounds, II-IV-V₂ compounds, ZMO compounds (where Z = an alkaline or alkali metal and M = a transition metal or rare earth metal element), oxides, phosphides, arsenides, sulfides, selenides, tellurides, chalcogenides, chalcopyrites and combinations thereof.

6. The catalyst system as defined in claim 1, 2, or 3, wherein said first semiconductor material

1 has an energy band gap greater than 1.6 eV.

7. The catalyst system as defined in claim 1, 2, or 3, wherein said first facilitating material comprises an element selected from Group VI and Group VII of the Periodic Table of Elements.

6 8. The catalyst system as defined in claim 1, 2, or 3, wherein said first facilitating material comprises a transition metal element or a rare earth metal element.

9. The catalyst system as defined in claim 1, 2, or 3, wherein said facilitating material comprises an element selected from the group consisting of Fe, Mn, Co, Ni, Cr, and Ti.

11 10. The catalyst system as defined in claim 1, wherein said first semiconductor material and/or said facilitating material has a dimension smaller than 1 μm .

16 11. The catalyst system as defined in claim 1, wherein said first semiconductor material and/or said facilitating material is a nano-scaled material with a dimension smaller than 100 nanometers.

21 12. The catalyst system as defined in claim 1, 2, or 3, further comprising a second semiconductor material with an energy gap Eg_2 different from Eg_1 , wherein said second semiconductor material is in electronic contact with said first facilitating material.

13. The catalyst system as defined in claim 1, 2, or 3, wherein said first semiconductor material is of n-type and said catalyst system further comprises a second semiconductor material of p-type in electronic contact with said first facilitating material.

26 14. The catalyst system as defined in claim 1, 2, or 3, further comprising a second semiconductor material in electronic contact with said first semiconductor material, wherein said second semiconductor material has an energy gap Eg_2 different from Eg_1 .

1 **15.** The catalyst system as defined in claim 14, further comprising at least a third semiconductor material, wherein said first, second and third semiconductor materials are connected in series.

16. The catalyst system as defined in claim 14, further comprising a second facilitating material in electronic contact with said second semiconductor material.

6 **17.** The catalyst system as defined in claim 1, 2, or 3, further comprising a second facilitating material in electronic contact with said first semiconductor material.

18. The catalyst system as defined in claim 17, wherein said first facilitating material comprises
11 a reduction catalyst and said second facilitating material comprises an oxidation catalyst.

19. A method for converting optical energy into chemical energy to drive a chemical reaction for producing hydrogen gas from an aqueous electrolyte, said method comprising:

 (A) suspending discrete photo-electrolytic catalysts in said electrolyte; and

16 (B) illuminating said catalysts with optical energy to produce hydrogen gas;

 wherein said catalysts comprises (a) a first semiconductor material with a non-zero energy gap E_g , which, in response to optical energy, generates electron-hole pairs as charge carriers; and (b) at least a first facilitating material in electronic contact with said semiconductor material to facilitate separation of the optical energy-generated electrons from the holes to reduce the
21 probability of charge carrier recombination.

20. The method as defined in claim 19, further comprising operating means to collect said hydrogen gas produced.

26 **21.** The method as defined in claim 19, wherein both said first semiconductor material and said first facilitating material have at least one dimension being nanometer-scaled, smaller than or equal to 100 nm.

22. The method as defined in claim 19, wherein at least one of said semiconductor material and

1 facilitating material is porous.

23. The method as defined in claim 19, wherein said optical energy is provided by solar radiation.

6 24. The method as defined in claim 19, 20, 21, 22 or 23, wherein said catalysts further comprise a second semiconductor material with an energy gap Eg_2 different from Eg_1 , wherein said second semiconductor material is in electronic contact with said first facilitating material.

11 25. The method as defined in claim 19, 20, 21, 22 or 23, wherein said first semiconductor material is of n-type and said catalysts further comprises a second semiconductor material of p-type in electronic contact with said first facilitating material.

16 26. The method as defined in claim 19, 20, 21, 22 or 23, wherein said catalysts further comprise a second semiconductor material in electronic contact with said first semiconductor material, wherein said second semiconductor material has an energy gap Eg_2 different from Eg_1 .

21 27. The method as defined in claim 24, wherein said catalysts further comprise at least a third semiconductor material and said first, second and third semiconductor materials are connected in series.

28. The method as defined in claim 24, wherein said catalysts further comprise a second facilitating material in electronic contact with said second semiconductor material.

26 29. The method as defined in claim 19, 20, 21, 22 or 23, wherein said catalysts further comprise a second facilitating material in electronic contact with said first semiconductor material.

30. The method as defined in claim 29, wherein said first facilitating material comprises a reduction catalyst and said second facilitating material comprises an oxidation catalyst.

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31. The method as defined in claim **19, 20, 21, 22** or **23**, wherein said first facilitating material comprises an electron-drawing atom, molecule, or ion.

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32. The method as defined in claim **19, 20, 21, 22** or **23**, wherein said first semiconductor material comprises an element or compound selected from the group consisting of group IV semiconductors, III-V compounds, II-VI compounds, mixed crystals of II-VI compounds, mixed crystals of III-V compounds, I-III-V₂ compounds, II-IV-V₂ compounds, ZMO compounds (where Z = an alkaline or alkali metal and M = a transition metal or rare earth metal element), oxides, phosphides, arsenides, sulfides, selenides, tellurides, chalcogenides, chalcopyrites and combinations thereof.

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33. The method as defined in claim **19, 20, 21, 22** or **23**, wherein said first semiconductor material has an energy band gap greater than 1.6 eV.

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34. The method as defined in claim **19, 20, 21, 22** or **23**, wherein said first facilitating material comprises an element selected from Group VI and Group VII of the Periodic Table of Elements.

35. The method as defined in claim **19, 20, 21, 22** or **23**, wherein said first facilitating material comprises a transition metal element or a rare earth metal element.

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36. The method as defined in claim **19, 20, 21, 22** or **23**, wherein said facilitating material comprises an element selected from the group consisting of Fe, Mn, Co, Ni, Cr, and Ti.